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## **Sensor Webs**

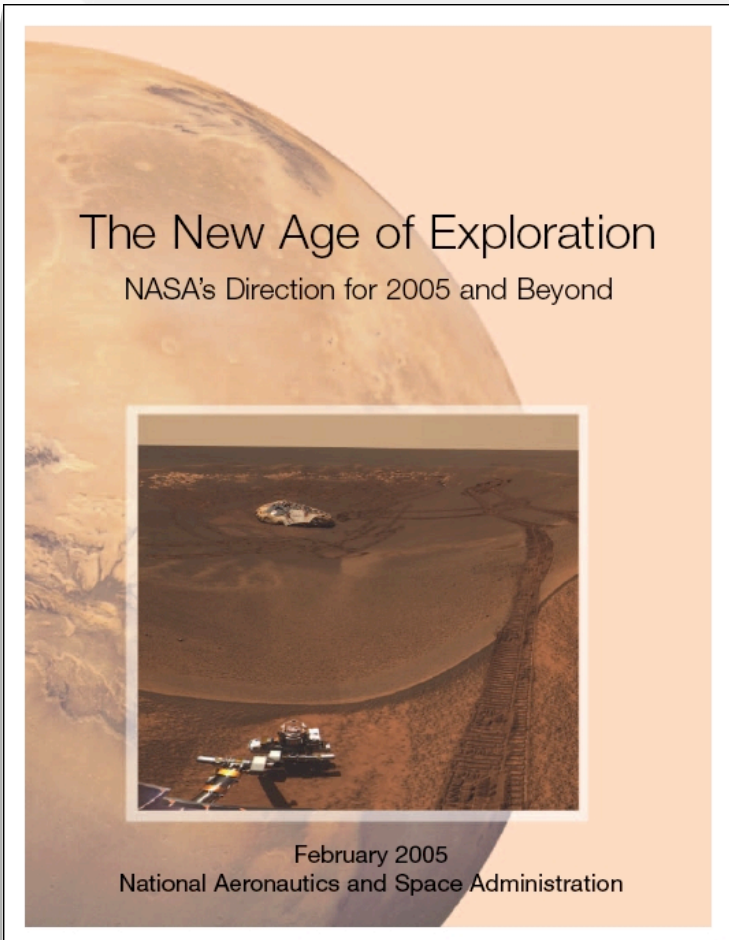
Maximizing Useful Science Return Using Dynamic  
Measurement Techniques and Adaptive Observing  
Strategies

# Agenda



- Science Missions: *Yesterday and Today*
- Sensor Webs: *Tomorrow*
- NASA/Goddard Sensor Web R&D
- Summary

*"...researchers envision an intelligent and integrated observation network comprised of sensors deployed to vantage points from the Earth's surface to deep space. This **Sensor Web** will provide timely, on-demand data and analysis to users..." [page 6]*

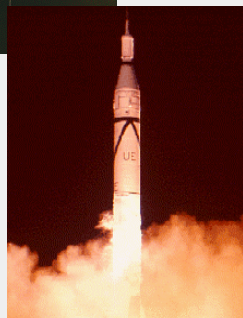


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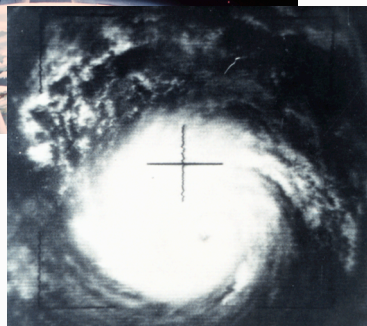
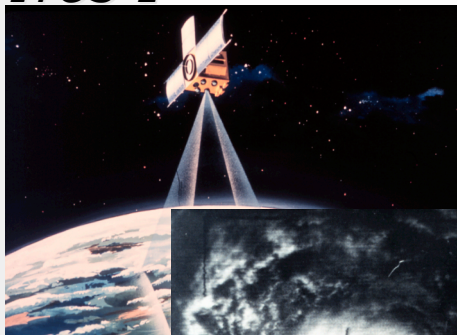
# Science Instruments & Missions: Yesterday...



*Explorer 1*



*ITOS-1*



1965



*GOES I-M*



1992

*Landsat-4*



1982



1958

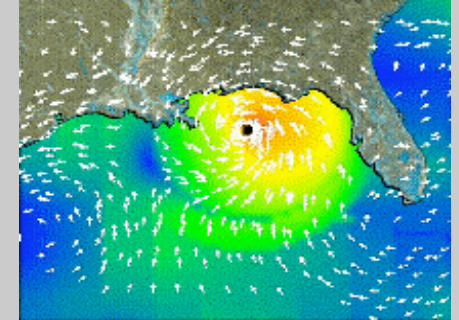
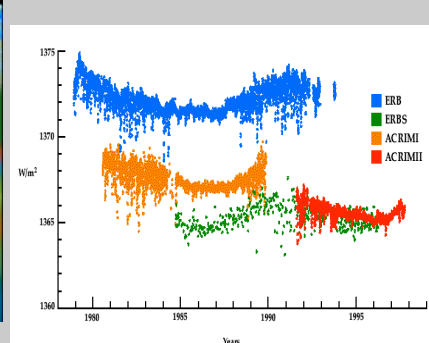
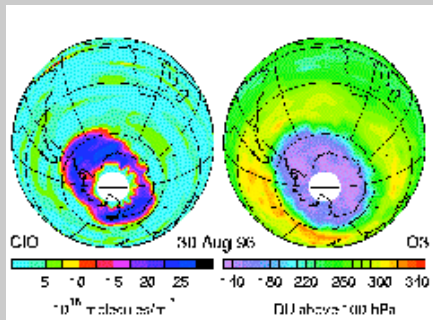
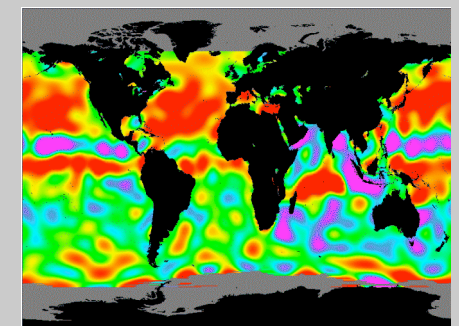
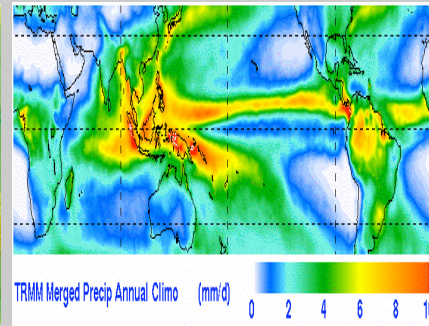
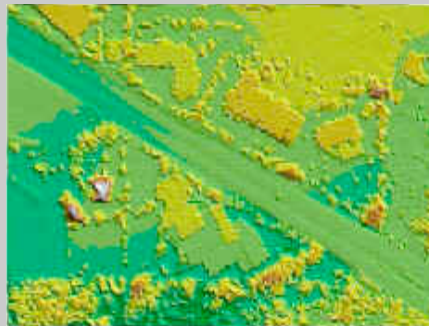
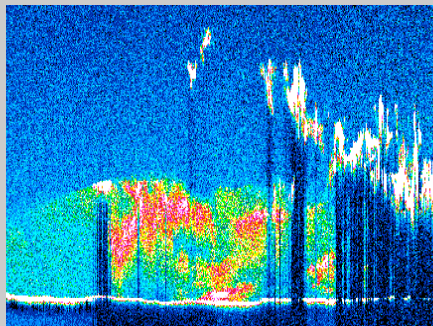
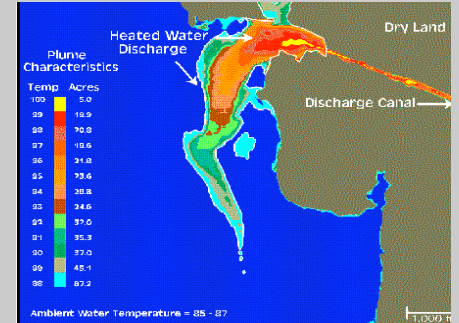
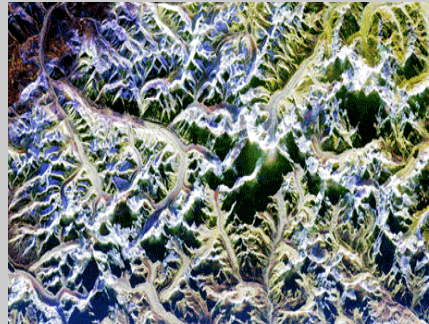
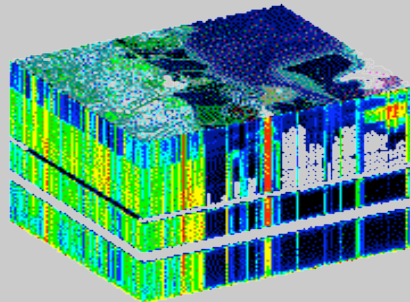
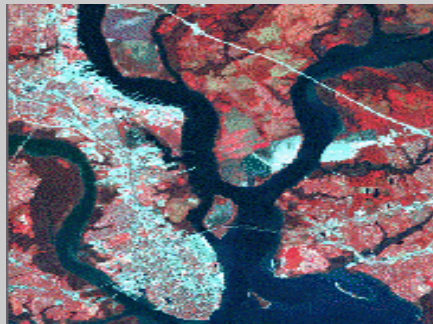


# Missions & Sensors: Today (1)





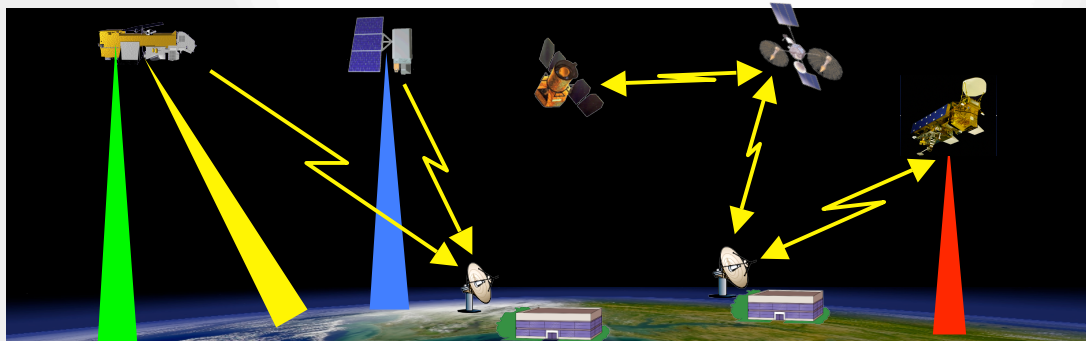
# Missions & Sensors: Today (2)



# Operations Concept: Today



- Science measurements and mission ops concepts by single, independent science instruments and platforms
- Taking initial steps toward integrated measurement systems
- No real time information sharing or sensor data fusion between instruments, platforms, or systems
- With a few exceptions, reactive & selectable sensor measurement modes are lacking
- Lack of (near) real-time, interoperable planning and scheduling systems to facilitate opportunistic science and discovery
- Interspacecraft communications: a “bent pipe” service for command uplinks and science data downlinks





# Future Vision

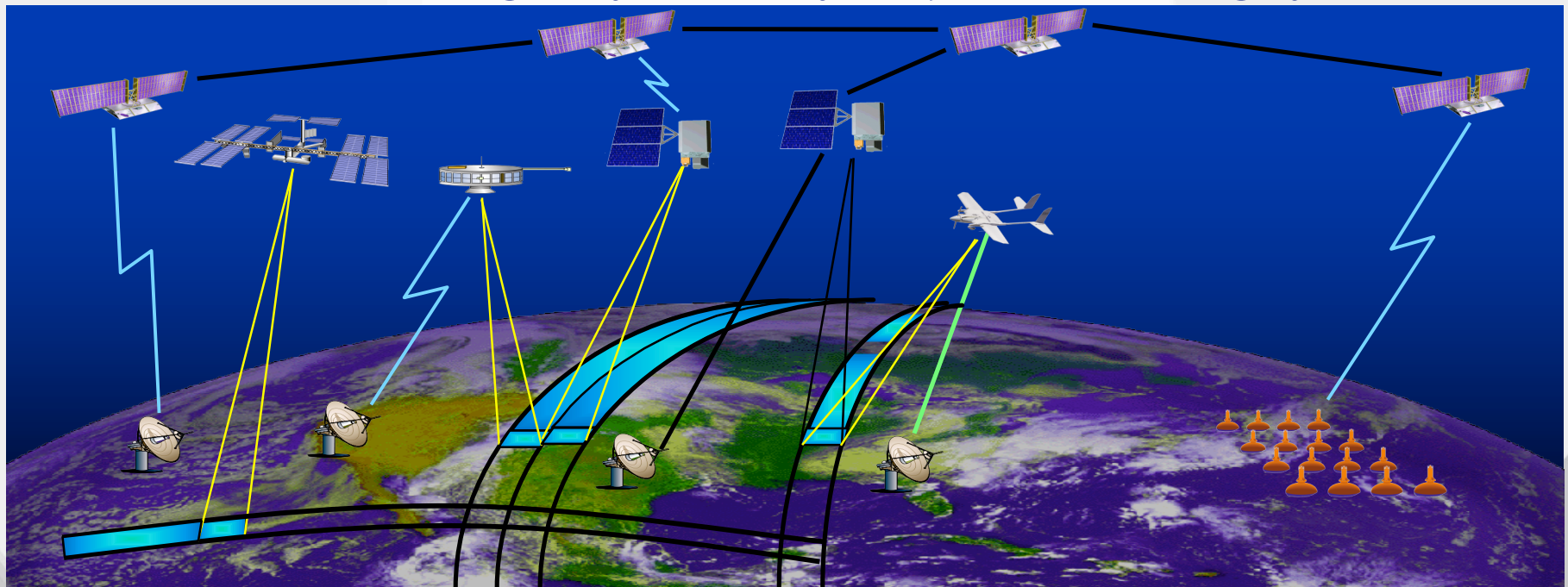
## A Global Sensor Web Observing System



*"The best way to be ready for the future is to invent it."*

*John Sculley – CEO, Apple Computer*

*A sensor web is a coherent set of distributed "nodes", interconnected by a communications fabric, that collectively behave as a single, dynamically adaptive, observing system.*

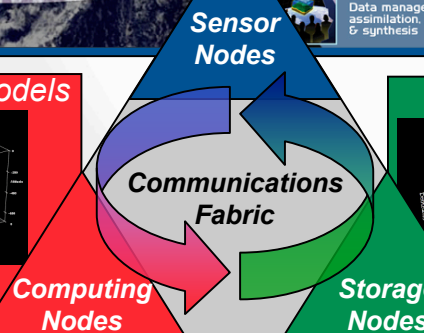
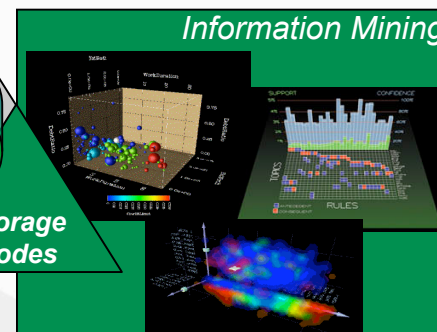
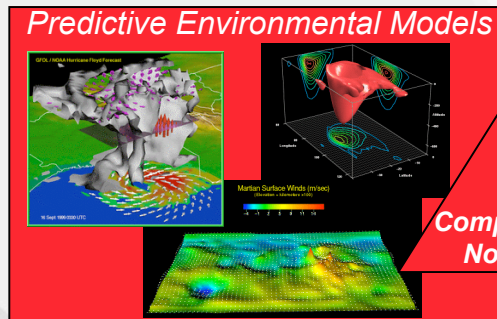
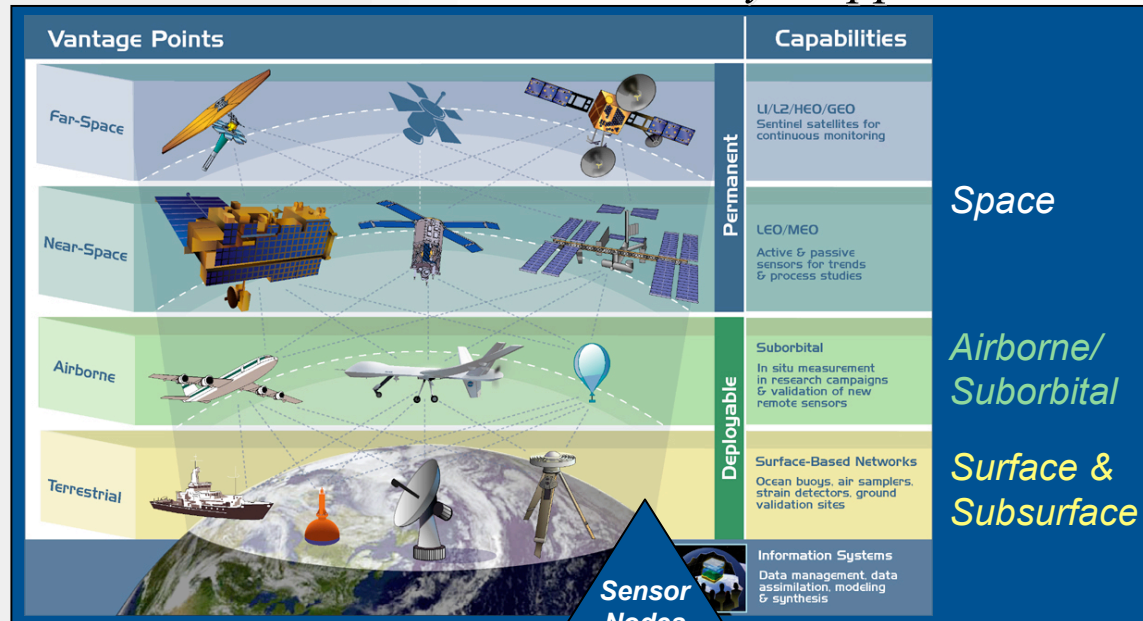


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# Maximizing Useful Science Return and Enabling New Applications

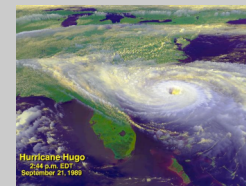
*"Life was simple before World War II. After that, we had systems." Rear Admiral Grace Murray Hopper*



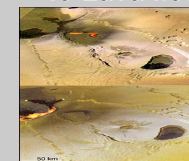
Volcanic Ash Plume



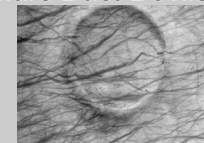
Hurricane



Io Lava flow



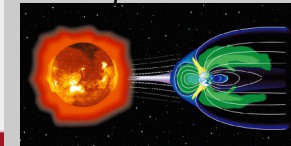
Mars Dust Devils



Gamma Ray Burst



Space Weather

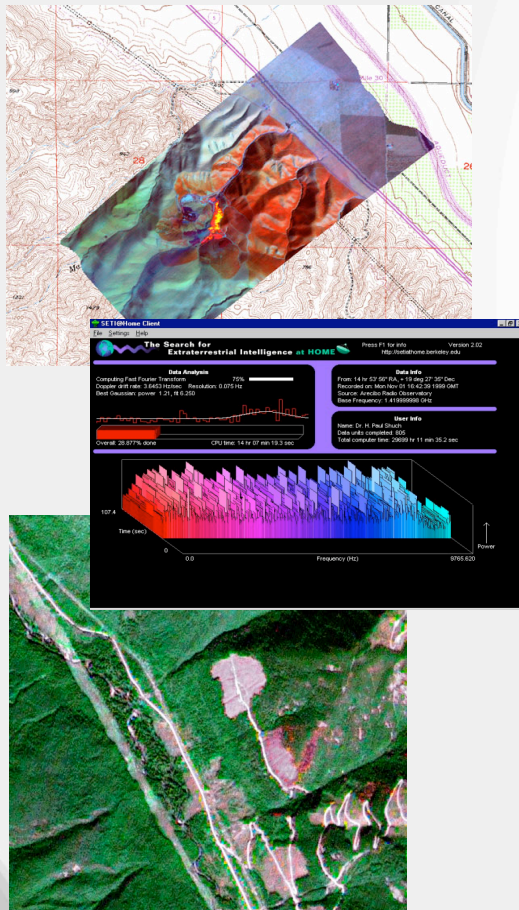


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# Autonomous Node Interactions

*"Nothing endures but change. There is nothing permanent except change. All is flux, nothing stays still." Heraclitus*



## *Responding to Change*

Node State	Action
<i>Event detection</i>	<ul style="list-style-type: none"> <li>▪ <i>Discriminate significant signals, features, patterns, ...</i></li> </ul>
<i>Event notification</i>	<ul style="list-style-type: none"> <li>▪ <i>Publish (subscribe to) event detection messages for use by other nodes</i></li> </ul>
<i>Event processing</i>	<ul style="list-style-type: none"> <li>▪ <i>Exchange sensor data and other information...</i></li> <li>▪ <i>Perform multi-sensor data fusion</i></li> </ul>
<i>Node reaction</i>	<ul style="list-style-type: none"> <li>▪ <i>Determine available resources by exchanging node state messages</i></li> <li>▪ <i>Modify science goals</i></li> <li>▪ <i>Plan &amp; schedule new measurements</i></li> </ul>

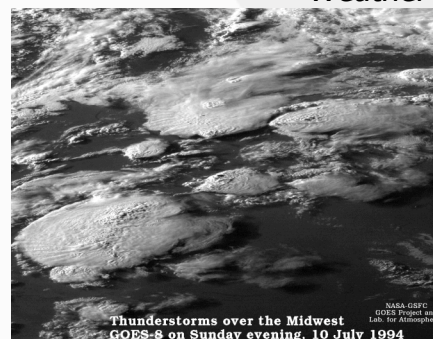
# Responding to Change

## Initiate New Node State

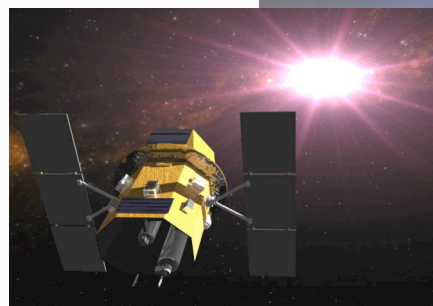
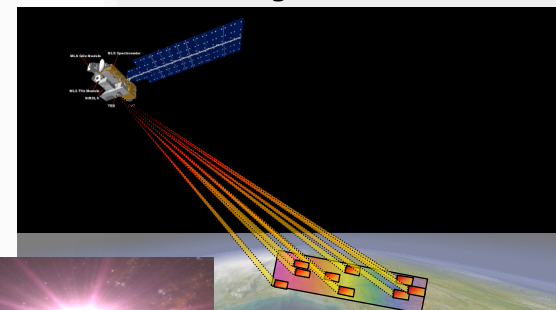


<i>Responding to Change</i>	
<b>New State</b>	<b>Examples</b>
<i>Spatial</i>	<ul style="list-style-type: none"> <li>Deploy sensor to new location; change measurement resolution, FOV, viewing geometry, ...</li> </ul>
<i>Temporal</i>	<ul style="list-style-type: none"> <li>Change sensor measurement frequency, ...</li> </ul>
<i>Spectral</i>	<ul style="list-style-type: none"> <li>Select phenomenon-unique sensor bands, ...</li> </ul>
<i>Data Assimilation &amp; Modeling</i>	<ul style="list-style-type: none"> <li>Generate new initial conditions; invoke nested-grid model; change model grid size or shape; ...</li> </ul>
<i>Organizational</i>	<ul style="list-style-type: none"> <li>Modify sensor net topology; form new sensor clusters; modify command &amp; control hierarchy, ...</li> </ul>
<i>Hardware &amp; software</i>	<ul style="list-style-type: none"> <li>Reconfigurable electronics; execute event specific algorithms</li> </ul>

GOES: Monitoring Severe Weather



AURA/TES: Targeted Measurements



Swift: Gamma Ray Bursts



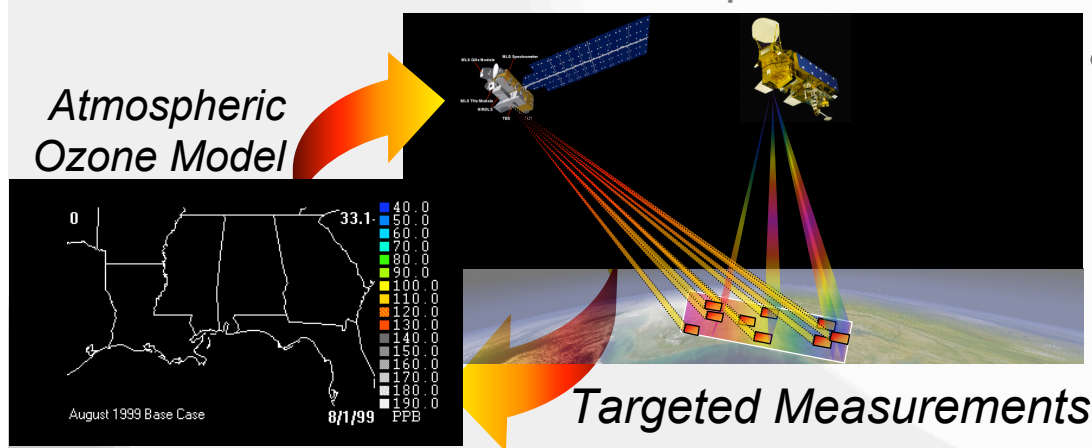
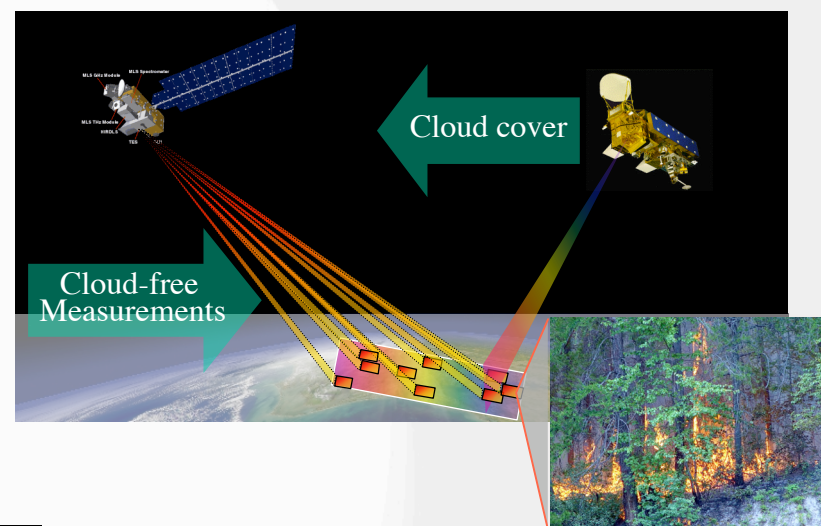


# Sensor Web Observing Systems

## *Representative Benefits*



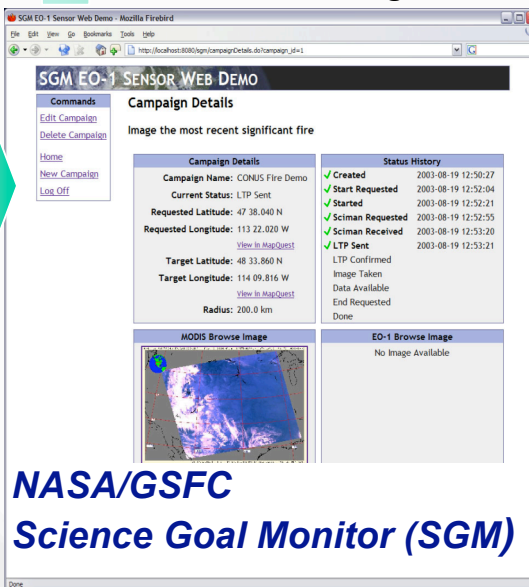
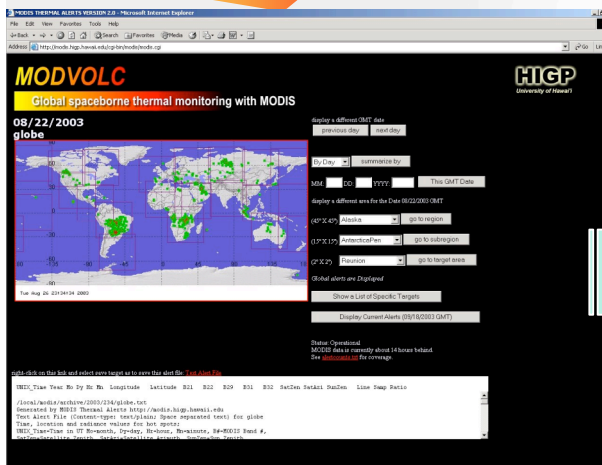
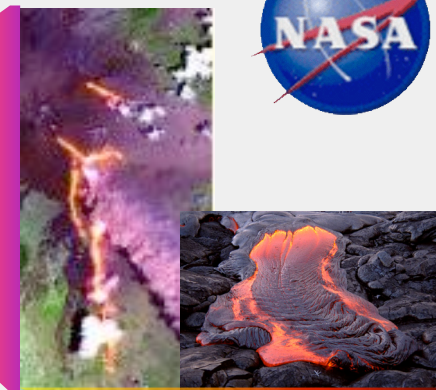
- Intelligent data collection
  - Maximize useful science return by improved utilization of instruments and platforms
- Event-driven observations
  - Task complementary instruments to measure rapidly evolving, transient, or variable events and phenomena



# EO-1 Targets Volcanoes



- ❑ Targets uplinked to EO-1 on-board planning & scheduling system (Casper)
- ❑ Use GOES cloud cover to make final target selection



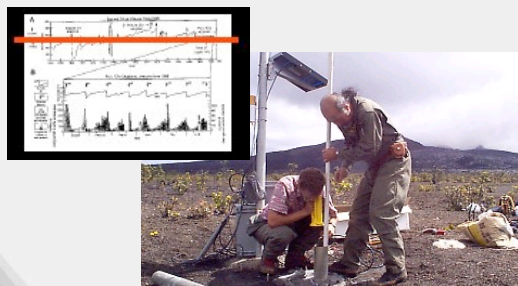
**NASA/GSFC**  
**Science Goal Monitor (SGM)**

**SGM monitors volcanic "hot spots" from MODIS, AVHRR imagery**



**On-board thermal detection algorithms**

- ❑ Re-image in < 8 hours
- ❑ Create browse images on-board
- ❑ D/L to Hawaii Volcano Observatory



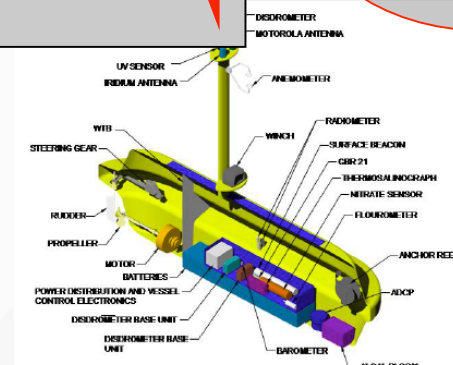
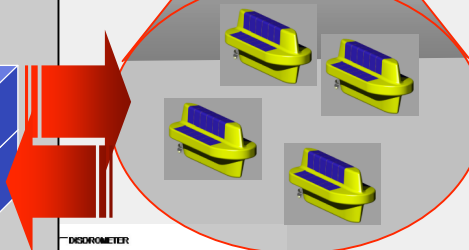
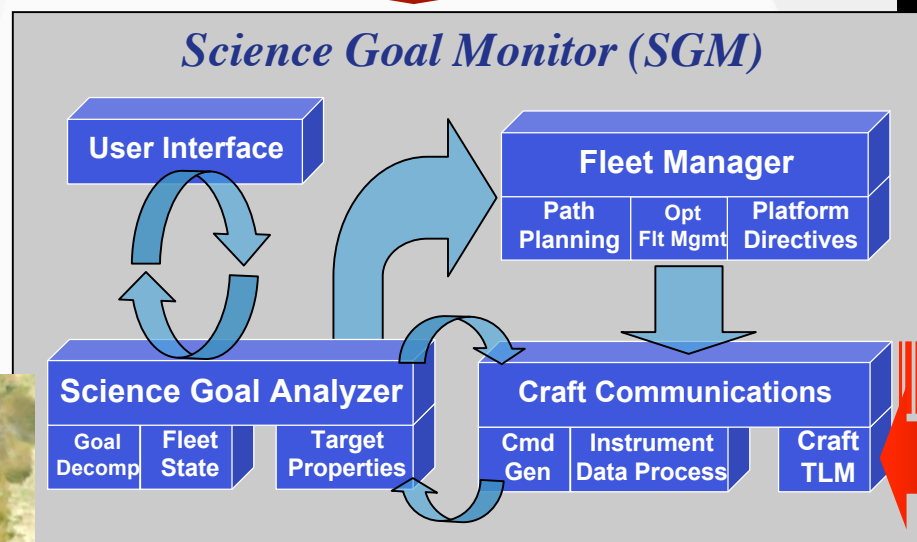
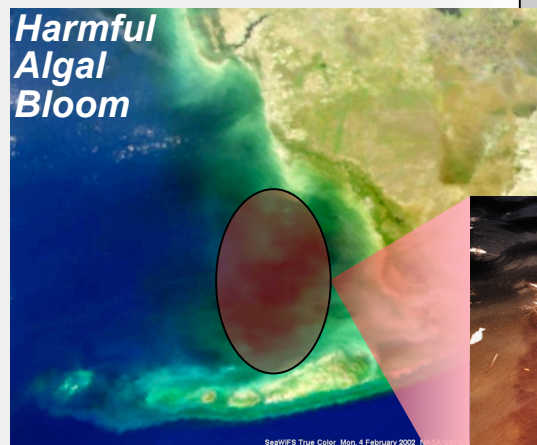
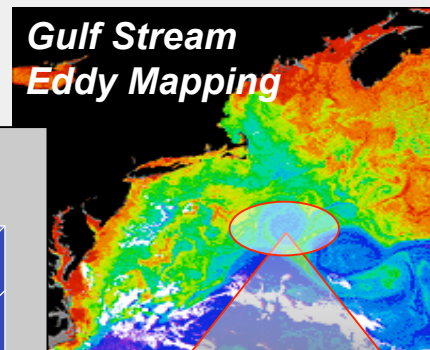
**In Situ Networked Sensors Kilauea, Hawaii**

**USGS**  
science for a changing world



**HVO**

# Adaptive Sensor Fleet: Science Goal Driven Fleet for in situ Marine Measurements

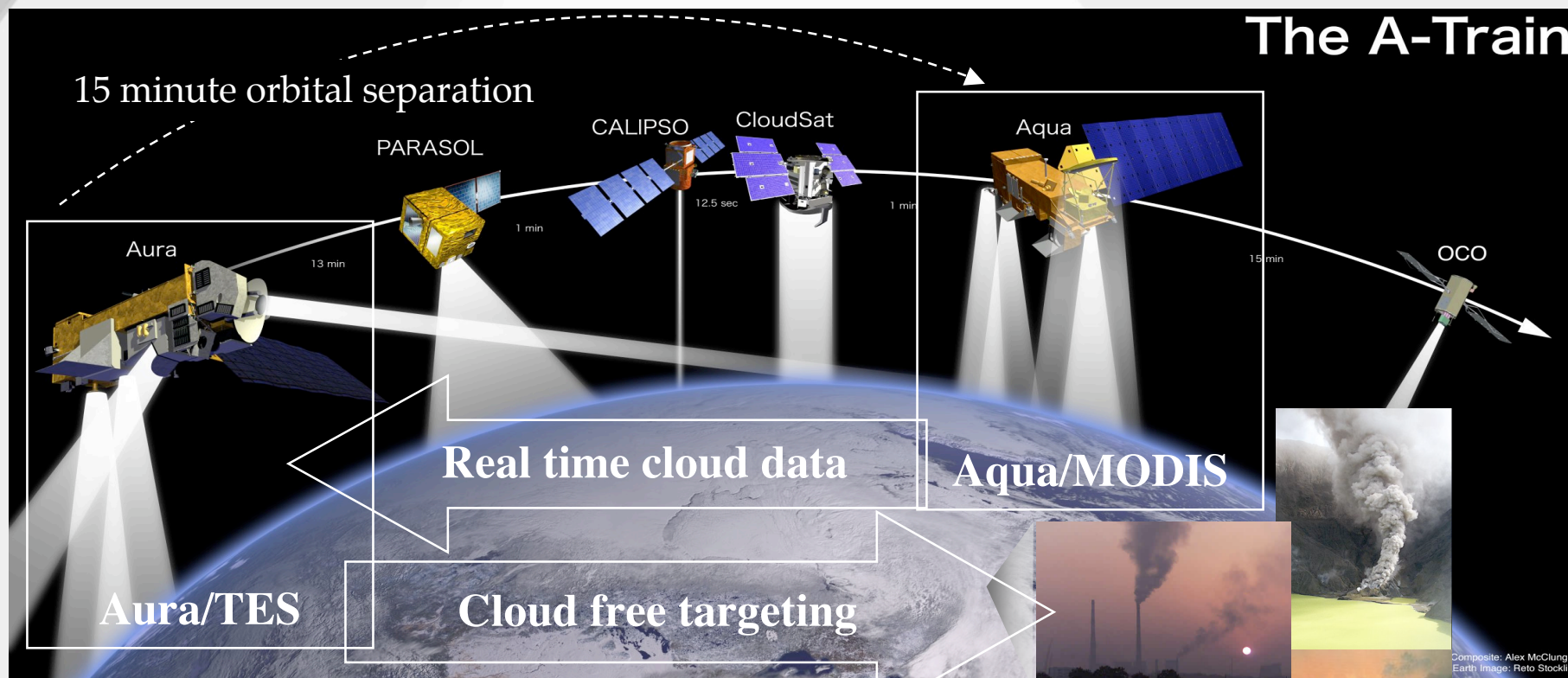


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**REFERENCE**



# “Event-driven” Sensor Web Simulation for Formation-flying Spacecraft



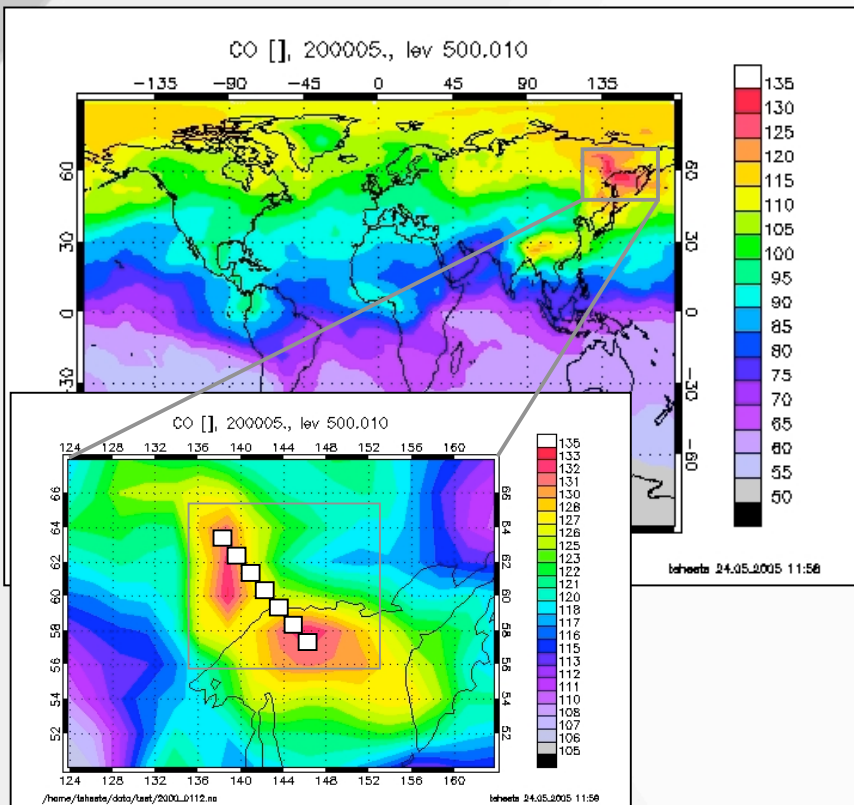
# STK/AVO: *Simulating Event-driven Targeted Cloud-free Measurements*



Aqua/Aura Movie

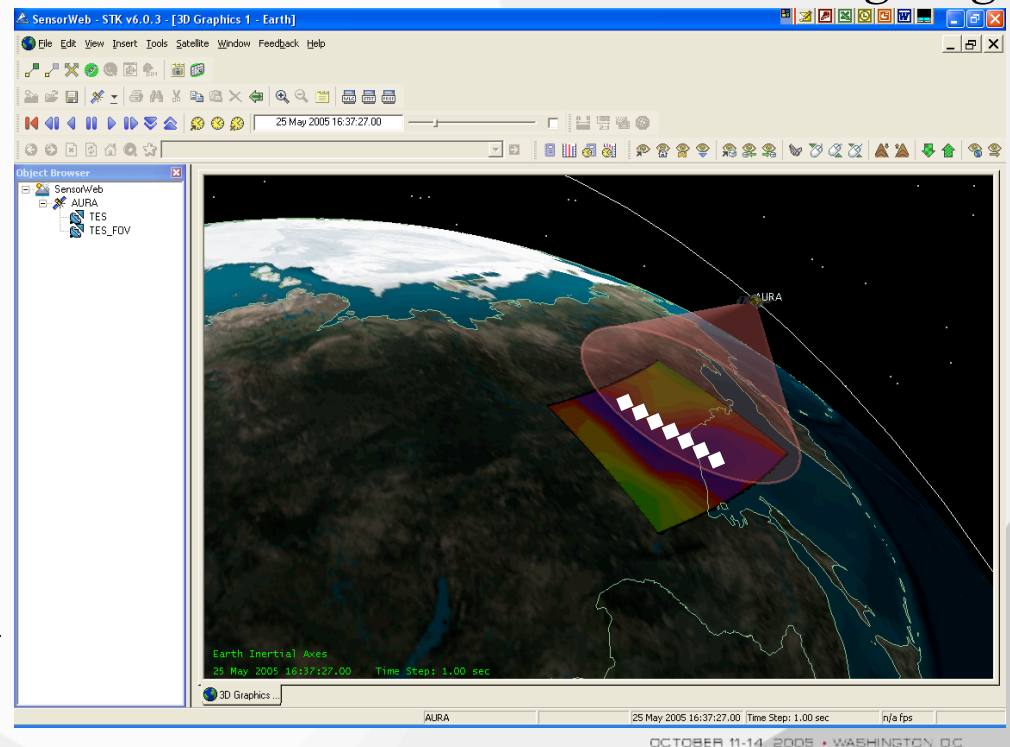


# Model-driven Sensor Web Simulation



*High CO concentration regions  
drives STK targeting simulation*

## *STK/AVO: Simulated Aura/TES targeting*

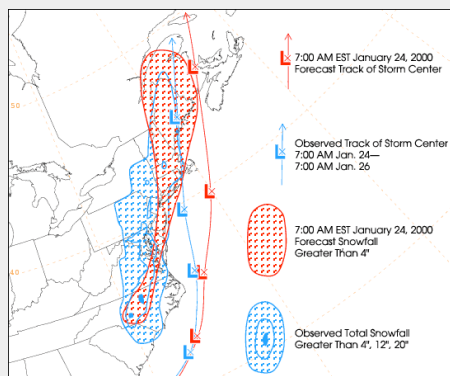




# Meteorological Observing System Sensor Web Simulator

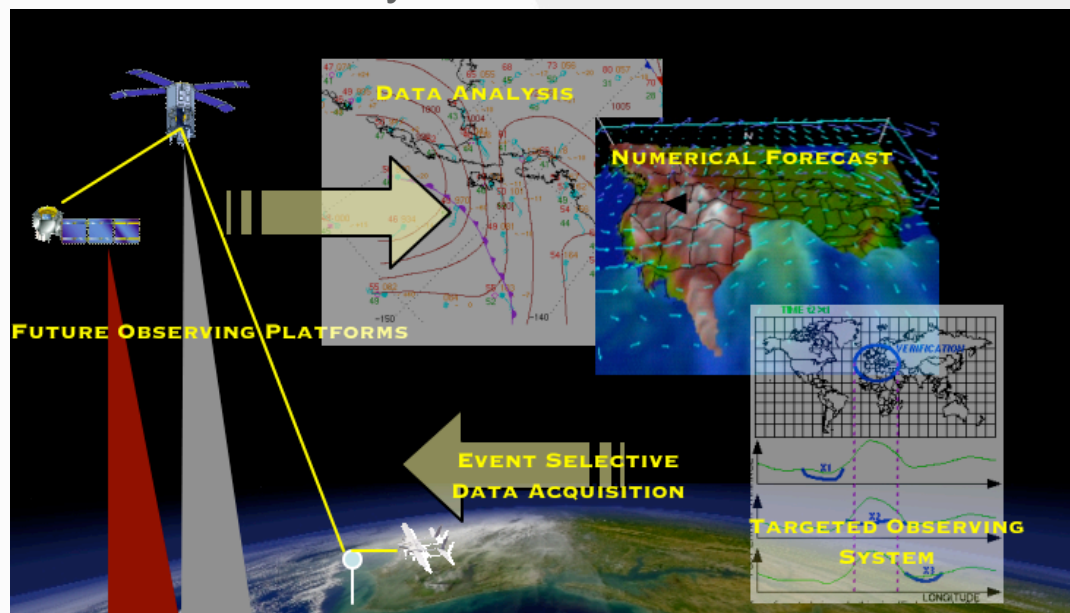


- Sensor webs would enable numerical forecast models to influence the observing system - potentially controlling error growth in the system
- ... BUT investing in the sensor web could be costly and would involve risk

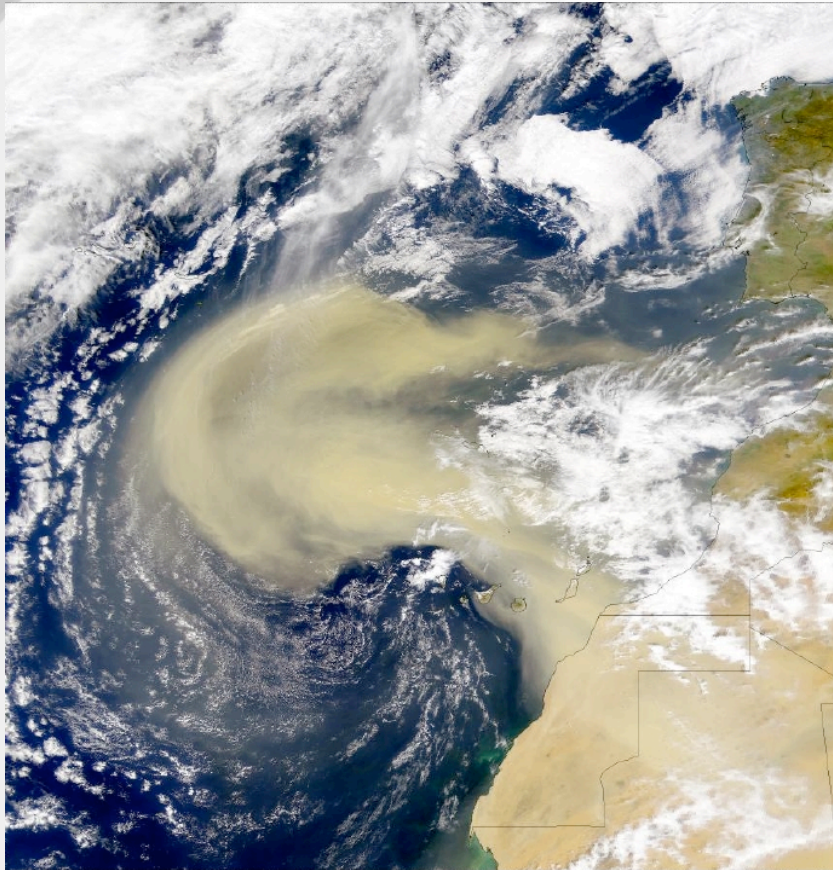


*Solution:*

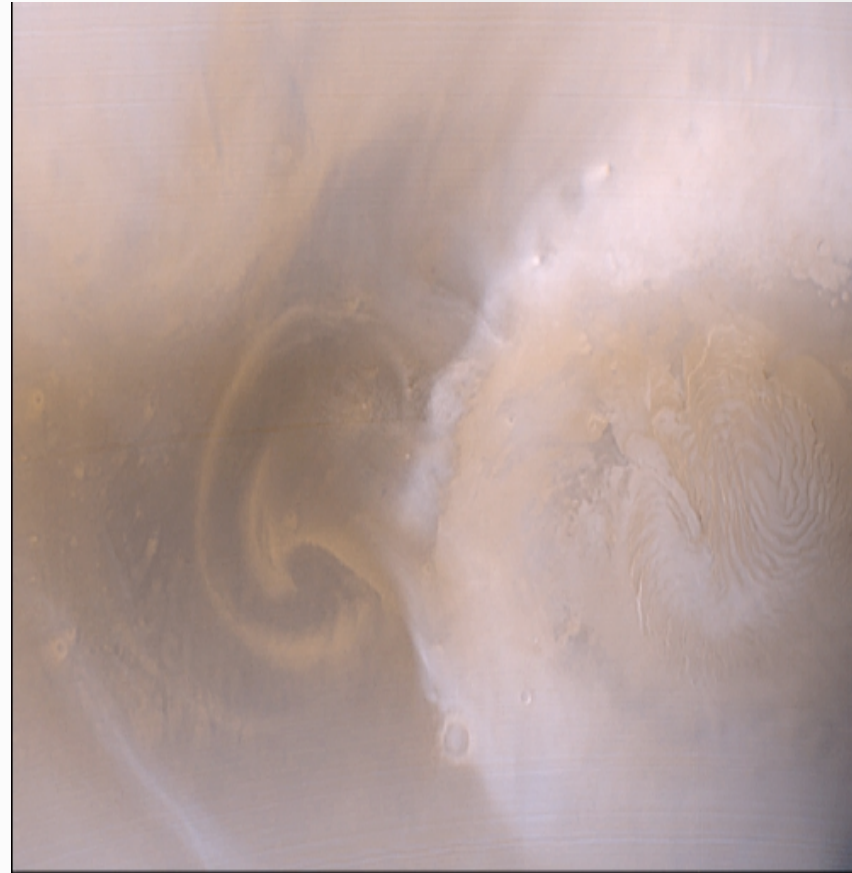
- Use Goddard Observing System Simulation Experiments (OSSEs) to construct real-world simulations of the atmosphere ("nature runs") that can then be sampled by a simulated observing system
- Objectively evaluate alternative dynamic measurement techniques & adaptive observing strategies



# *Applying Sensor Webs to Similar Planetary Phenomena and Events (1)*



*Earth Dust Storm*



*Mars Dust Storm*

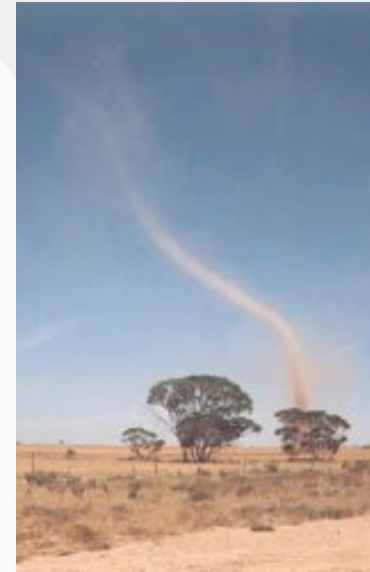




# *Applying Sensor Webs to Similar Planetary Phenomena and Events (2)*



Credit: NASA



Credit: NOAA



0000

Credit: University of Arizona, Department of Planetary Sciences



# Summary



- *Earth & space science events and future exploration activities are intrinsically dynamic*
- Future observing systems & sensors should facilitate
  - Dynamic, reactive measurement techniques
  - Collaborative, adaptive observing strategies
  - Horizontal information fusion
- *Sensor Web-enabled science instruments and observing systems*
  - Complement current mission ops concepts
  - Possess capability to react to unanticipated events, uncharted territory, and spontaneous needs
  - Benefits the Earth and space-sciences, and NASA's Vision for Space Exploration
- *Simulation & visualization tools facilitate "What if?" analyses*

